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DISCUSSION OF CONSUMPTIVE USE OF WATER

(*Published in October, 1951*)

By George H. Hargreaves, William W. Donnan, and Harry F. Blaney

IRRIGATION AND DRAINAGE DIVISION

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Technical Division	*Proceedings-Separate Number*
Air Transport	108, 121, 130, 148, 163 (Discussion: D-23, D-43, D-75, D-93, D-101, D-102, D-103, D-108)
City Planning	58, 60, 62, 64, 93, 94, 99, 101, 104, 105, 115, 131, 138, 148, 151, 152, 154 (Discussion: D-16, D-23, D-43, D-60, D-62, D-65, D-86, D-93, D-99, D-101, D-105, D-108, D-115)
Construction	130, 132, 133, 136, 137, 145, 147, 148, 149, 150, 152, 153, 154, 155, 159, 160, 161, 162 (Discussion: D-3, D-8, D-17, D-23, D-36, D-40, D-71, D-75, D-92, D-101, D-102, D-109, D-113, D-115)
Engineering Mechanics	122, 124, 125, 126, 127, 128, 129, 134, 135, 136, 139, 141, 142, 143, 144, 145, 157, 158, 160, 161, 162 (Discussion: D-24, D-33, D-34, D-49, D-54, D-61, D-96, D-100)
Highway	138, 144, 147, 148, 150, 152, 155, 163 (Discussion: D-XXVIII, D-23, D-60, D-75, D-101, D-103, D-105, D-108, D-109, D-113, D-115)
Hydraulics	107, 110, 111, 112, 113, 116, 120, 123, 130, 134, 135, 139, 141, 143, 146, 153, 154, 159 (Discussion: D-90, D-91, D-92, D-96, D-102, D-113, D-115)
Irrigation and Drainage	129, 130, 133, 134, 135, 138, 139, 140, 141, 142, 143, 146, 148, 153, 154, 156, 159, 160, 161, 162 (Discussion: D-97, D-98, D-99, D-102, D-109)
Power	120, 129, 130, 133, 134, 135, 139, 141, 142, 143, 146, 148, 153, 154, 159, 160, 161, 162 (Discussion: D-38, D-40, D-44, D-69, D-70, D-71, D-76, D-78, D-79, D-86, D-92, D-96, D-102, D-109, D-112)
Sanitary Engineering	55, 56, 87, 91, 96, 106, 111, 118, 130, 133, 134, 135, 139, 141, 149, 153 (Discussion: D-29, D-37, D-56, D-60, D-70, D-76, D-79, D-80, D-84, D-86, D-87, D-92, D-93, D-96, D-97, D-99, D-102, D-112)
Soil Mechanics and Foundations	43, 44, 48, 94, 102, 103, 106, 108, 109, 115, 130, 152, 155, 157 (Discussion: D-86, D-103, D-108, D-109, D-115)
Structural	133, 136, 137, 142, 144, 145, 146, 147, 150, 155, 157, 158, 160, 161, 162, 163 (Discussion: D-51, D-53, D-54, D-59, D-61, D-66, D-72, D-77, D-100, D-101, D-103, D-109)
Surveying and Mapping	50, 52, 55, 60, 63, 65, 68, 121, 138, 151, 152 (Discussion: D-60, D-65)
Waterways	120, 123, 130, 135, 148, 154, 159 (Discussion: D-8, D-9, D-19, D-27, D-28, D-56, D-70, D-71, D-78, D-79, D-80, D-112, D-113, D-115)

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DISCUSSION

GEORGE H. HARGREAVES,[33] A. M. ASCE.—A long needed stimulus for additional research in irrigation requirements has been provided by Mr. Blaney. Not only is this a matter of importance in the United States but also in the irrigated areas of the world. Engineers everywhere need a better understanding of this problem in order that the benefits of irrigation may be extended by the prevention of waste. In Latin America a sound technical basis must be provided for substituting a beneficial use criterion for the rule "one liter per second per hectare." An example of the need for irrigation requirement data can be had from the irrigated areas near Lima and Piura in Peru. Both areas depend almost entirely on irrigation, the mean annual rainfall being 1.4 in. and 3.5 in., respectively. During a 12-month growing season evaporation at Piura averages 4.4 times that at Lima.

Irrigation in the tropics is becoming increasingly important. Monthly irrigation requirement data based on monthly consumption-use factors, as suggested by Mr. Blaney, or on the transfer of monthly consumptive-use data making use of evaporation data, are needed to determine the needs for irrigation and probable crop benefits. At Aux Cayes, Haiti, with a mean annual rainfall of 83 in., the need for irrigation is not generally recognized. However, this area has a definite 4-month to 5-month dry season and, based on estimated consumptive-use requirements, moisture deficiencies occur one third of the time or oftener except during May, August, and October in the rainy season.

Use of Evaporation Data.—Very briefly Mr. Blaney mentions the use of evaporation in estimating evapo-transpiration. More space in the discussion should be given this approach and its use should be more widely encouraged. Assuming comparable conditions of stage of growth, leaf surface area, and irrigated practice, the water requirement of a crop is closely proportional to evaporation from a water surface during the growing season. This relationship is not constant month by month throughout the growing season as transpiration increases proportionally with increasing leaf surface area. However, if irrigation requirements at comparable stages of growth are related to evaporation, this fact forms the most practical means of transferring irrigation requirements and consumptive-use data from one area to another.

Use of Emperical Formulas.—By using Eq. 1 and substituting evaporation, e, in place of consumptive use, u, values of k_m were computed based on temperature, humidity, and Piche evaporometer records in Peru. Average values of $k_m = e/c$ were computed for the growing season at several stations. At Lima the computed annual K_a for the Piche evaporometer is 0.015 whereas at Piura, the computed K_a is 0.036. In each case values of k_m were fairly constant throughout the 12-month growing season. From this it would appear that use of Eq. 1 is limited both by the lack of available relative humidity data and the difficulties involved in choosing suitable k_m-values. Evaporation records from

NOTE.—This paper by Harry F. Blaney was published in October, 1951, as *Proceedings-Separate No. 91*. The numbering of footnotes and tables in this Separate is a continuation of the consecutive numbering used in the original paper.

[33] Civ. Engr., Inst. of Inter-American Affairs, Port-au-Prince, Haiti.

the Weather Bureau type pans are available for many stations, particularly in California.[34] These can be used for evaluating the formula $u = kf$ by substituting evaporation, e, in place of the consumptive use. Then $k = e/f$. Values of k were computed for the growing season at forty-six evaporation stations. It was found that these values fell into natural classifications—coastal plain, uplands and mountains, Central Valley, and desert. These values of k are given in Table 9. For the climatic zones in California k-values

TABLE 9.—VALUES OF k FROM THE FORMULA $k = e/f$ OR RATIO OF EVAPORATION OF CONSUMPTIVE-USE FACTOR

Location or area	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
California:												
Entire state	...	...	1.03	1.15	1.28	1.36	1.43	1.40	1.30	1.08	0.92	...
Coastal Plain	...	...	0.86	0.99	1.10	1.15	1.19	1.12	1.06	0.89	0.66	...
Uplands and mountains	...	...	0.99	1.04	1.17	1.26	1.37	1.36	1.27	1.08	0.95	...
Desert	...	1.41	1.65	1.86	1.90	1.94	1.97	1.87	1.74	1.53	1.48	...
Central Valley	...	...	...	1.09	1.33	1.51	1.56	1.52	1.35	0.97	...	...
Davis	...	...	...	1.08	1.38	1.37	1.43	1.42	1.34	1.03	...	...
Haiti:												
Port-au-Prince	0.94	0.93	0.97	1.04	0.95	1.01	1.02	0.93	1.00	0.98	0.81	0.76
Peru[a]:												
Piura	1.51	1.63	1.65	1.90	1.34	1.71	1.52	1.58	1.55	1.28	1.42	1.61
Paramonga	0.81	0.82	0.80	0.75	0.53	0.59	0.50	0.46	0.50	0.51	0.75	0.64
Lima	0.56	0.56	0.52	0.46	0.36	0.27	0.29	0.27	0.28	0.35	0.41	0.46
Tacna	0.80	0.82	0.79	0.60	0.54	0.43	0.47	0.52	0.52	0.60	0.65	0.77
Cusco	1.54	1.47	1.65	...	...	...	...	...	...	1.79	1.78	1.60

[a] Coefficients for Peru are based on Piche evaporometer measurements, which are believed to give about 80% of Weather Bureau type pan evaporation. Evaporation data for California and Haiti are from the Weather Bureau type pan.

increase with temperature averaging 38% to 43% higher in July than for the first month of the growing season. If evaporation is interchangeable with consumptive use in Eq. 5 then evaporation must vary directly as the monthly consumptive use of factor, f. The data presented in Table 9 show that this assumption, although useful as an index of irrigation requirements, is subject to considerable error.

Conclusions.—Based on the Piche evaporometer records, the monthly use index (c being the climatic factor) was found to correlate well with evaporation at a given location. This relationship varies with the location of the station probably because of other unmeasured climatic factors, indicating that the application of Eq. 1 to irrigation problems will be difficult. A study of available evaporation records from the Weather Bureau type pans indicates that the monthly consumptive-use factor, f, does not (as assumed by Mr. Blaney) vary directly with evaporation and consumptive use. However, from the California data, average month-by-month coefficients based on the ratio of evaporation to consumptive-use factors can be computed for a given climatic zone such as the coastal plain or the desert. These coefficients should provide a useful method for transferring irrigation requirement and consumptive-use data when evaporation data are not available. Month-by-month coefficients will provide data for canal capacity design and the analysis of irrigation requirements and benefits in tropical areas where, under conditions of high annual rainfall, the

[34] "Evaporation from Water Surfaces in California, Basic Data," by Arthur A. Young, *Bulletin No. 54 A*, California State Div. of Water Resources, Sacramento, Calif., 1948.

month-by-month distribution of available moisture is one of the principal factors limiting agriculture production.

WILLIAM W. DONNAN,[35] A. M. ASCE.—Throughout the United States engineers are faced with the paradox of expanding water use and dwindling supplies. The conservation, preservation, and beneficial use of these water supplies is a challenging problem that can be solved only by careful analysis. Of particular interest to the writer is the section dealing with the evaluation of consumptive use by "Correlation of Water Use, Climatological Data and Other Data." During the course of an investigation (reported in 1952[36]), the Division of Irrigation Engineering and Water Conservation, SCS, was called upon to determine the annual consumptive use of water in the Los Angeles West Coast Basin for a 20-year previous period. These data were needed so that an adjudication could be made of the present available supply and long-term mean supply. By securing published Weather Bureau data on temperatures, precipitation, and evaporation in the West Coast Basin of Los Angeles County, it was possible to make valid estimates of water consumption using the Blaney-Criddle method.[27] In making these estimates, the long-term mean unit consumptive use was computed for each land-use classification. These unit values were then modified by the temperature and precipitation occurring in each individual year. The resultant consumptive-use values were applied to land-use acreages for the individual years of the study. When applied to the inflow-outflow equations of the hydrologic balance for the basin, these data made it possible to determine the degree of overdraft on the underground water supplies.

The question may arise in the minds of some readers as to whether a determination of unit consumptive use by the correlation method gives valid estimates. In an investigation[37] of irrigation and drainage problems in the San Fernando Valley in cooperation with the city engineer of Los Angeles, the writer and others had a chance to check on the validity of these estimates.

San Fernando Valley comprises about two fifths the area of the City of Los Angeles. Since roughly one fourth of its 130,000 acres is still used for agriculture, it presents a unique combination of urban and rural land use. The valley is an enclosed basin with a 400-sq-mile watershed draining to the valley from surrounding foothills and mountains and with a confined outlet at the Dayton Avenue narrows. In making an analysis of input-outflow in this basin over a 20-year period, measured data on each factor were available. The precipitation on the basin is measured at about forty different locations.

All importations to the basin are carefully metered. The exported water is sold through domestic meters. Sewage out of the basin is metered. The surface outflow at the Dayton Avenue gaging station is measured accurately.

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[35] Drainage Engr., SCS Research, U. S. Dept. of Agri., Los Angeles, Calif.

[36] "West Coast Basin Reference, Draft of Report by Referee," by Dept. of Public Works, State of California, Referee, acting through the State Engr., Sacramento, Calif., February, 1952.

[27] "Determining Water Requirements in Irrigated Areas from Climatological and Irrigation Data," by Harry F. Blaney and Wayne D. Criddle, Div. of Irrigation and Water Conservation, SCS, U. S. Dept. of Agri., SCS-TP-96, Washington, D. C., 1950.

[37] "Ground Water and Drainage Investigations in San Fernando Valley, Los Angeles, California," by William W. Donnan, G. Marvin Litz, and V. S. Aronovici, Div. of Irrig. Eng. and Water Conservation, SCS, U. S. Dept. of Agri., Los Angeles, Calif., 1950 (mimeographed publication).

A small amount of subsurface outflow was accounted for. Because there are about one hundred and fifty observation wells in the valley floor, an accurate ground-water contour map could be drawn for each year and yearly changes in underground storage determined. The largest item in the hydrologic equation, comprising approximately 65% of the aggregate outflow, was the consumptive use. This was computed for each individual land-use classification and modified by yearly temperatures and precipitation. The hydrologic balance, equating input (consisting of precipitation and imports) to outflow (consisting of surface and subsurface runoff, exports, sewage, consumptive use, and plus or minus change in underground storage) came within 1.6% of checking each other.

HARRY F. BLANEY,[38] M. ASCE.—The discussion by Mr. Hargreaves calls attention to the world-wide expansion of irrigated areas resulting from the foreign program of the United States. The writer has received requests for more details on procedure in computing consumptive use from Austria, Brazil, Egypt, Greece, India, and Mexico. Eq. 5 is being widely used. For humid areas the seasonal coefficient K shown in Table 6 should be reduced by about 10%. Table 10 illustrates the computations necessary to determine monthly consumptive use.

TABLE 10.—COMPUTED NORMAL CONSUMPTIVE USE OF WATER BY GRASS PASTURE, VICTORIA, TAMAULIPAS, MEXICO

Month (Tables 10 and 11)	Mean monthly temperature (t)	Daytime hours (p%)	Consumptive Use		
			Factor[a] (f)	Coefficient[b] (k)	Product[c] u, in inches
(1)	(2)	(3)	(4)	(5)	(6)
April	77.0	8.60	6.62	0.60	4.0
May	80.2	9.29	7.45	0.65	4.8
June	82.0	9.18	7.53	0.70	5.3
July	83.3	9.39	7.82	0.75	5.9
August	83.8	9.04	7.58	0.75	5.7
September	79.9	8.31	6.64	0.65	4.3
October	74.8	8.10	6.06	0.60	3.6

[a] $f = \frac{t \times p}{100}$ = monthly consumptive-use factors. [b] k = monthly coefficient. [c] $u = kf$ = monthly consumptive use.

TABLE 11.—MONTHLY CONSUMPTIVE-USE COEFFICIENTS k FOR CROPS AND NATURAL VEGETATION[a]

Salinas	Corona	Davis[c]		Oceanside[d]	
Alfalfa[b]	Citrus[c]	Prunes	Tomatoes	Cottonwood trees	Tules
(2)	(3)	(4)	(5)	(6)	(7)
0.60	0.46	0.42	...	1.11	0.89
0.70	0.52	0.55	...	1.24	1.14
0.80	0.52	0.94	0.44	1.27	1.16
0.85	0.57	0.90	0.55	1.49	1.26
0.85	0.61	0.65	0.94	1.48	1.16
0.85	0.61	0.48	0.94	1.45	1.16
0.70	0.60	0.43	0.77	...	1.01

[a] Developed from data observed in the State of California. [b] Harry F. Blaney and Orson W. Israelsen. [c] Harry F. Blaney and G. Marvin Litz. [d] Harry F. Blaney and Paul A. Ewing.

In this paper the writer did not assume (as indicated by Mr. Hargreaves) that the monthly consumptive-use factor f in Eq. 5 varies directly with evaporation and consumptive-use. Coefficient K in Table 6 are seasonal values. When monthly values of k are available, the writer has recommended in other publications[26, 39] that they be used. Also, Fig. 2 and Table 4 indicate that the

[38] Prin. Irrig. Engr., Div. of Irrig. Eng. and Water Conservation, SCS, Research, U. S. Dept. of Agri., Los Angeles, Calif.

[26] "Irrigation Practice and Consumptive Use of Water in Salinas Valley, California," by Harry F. Blaney and Paul A. Ewing, Div. of Irrigation and Water Conservation, SCS, U. S. Dept. of Agri., Los Angeles, Calif., June, 1946.

[39] "Irrigation Principles and Practices," by Orson W. Israelsen, John Wiley & Sons, Inc., New York, N. Y., 1950, p. 311.

monthly value of k may vary. Monthly coefficients developed by the writer, based on measured consumptive u'-values and temperatures t (as reported by Orson W. Israelsen,[39] by Harry F. Blaney and G. Marvin Litz,[40] and by Harry F. Blaney and Paul A. Ewing[26]), are shown in Table 11. Monthly evaporation coefficients k, similar to those given for Weather Bureau pans by Mr. Hargreaves in Table 9, have been presented by the writer in reports on Salinas Valley,[26] California, and other areas.

The values of k for evaporation from pans presented by Mr. Hargreaves in Table 9 are useful in estimating monthly consumptive use, particularly phreatophytes such as alfalfa, willows, tules, and salt cedar. However, the writer has observed that monthly evaporation may not indicate the relative monthly evapo-transpiration for some agricultural crops such as citrus. The coefficients shown in Table 9 for evaporation from Weather Bureau pans are useful in estimating evaporation from reservoirs when reduced to evaporation from large water surfaces by a correction factor varying from 0.65 to 0.80. However, some physicists have questioned their value as well as the reliability of Piche evaporomenter measurements for estimating evaporation from reservoir or lake surfaces.

Mr. Donnan's reference to the Los Angeles West Coast Basin study illustrates the value of consumptive-use data in the adjudication of water rights.

TABLE 12.—EXAMPLE OF COMPUTATIONS OF SEASONAL CONSUMPTIVE-USE AND IRRIGATION REQUIREMENTS FOR CROPS IN THE MONTROSE AREA, COLORADO

Explanation of Column Headings—

Col. 3. F = Sum of monthly consumptive-use factors (f) for the growing or irrigation season.
Col. 4. K = Empirical consumptive-use coefficient determined experimentally.
Col. 5. $U = K F$ = Consumptive use for growing or irrigation season in inches.
Col. 6. R = Sum of monthly precipitation for growing or irrigation season, in inches.
Col. 7. E = Field irrigation efficiency (percentage).
Col. 8. $I = \frac{U - R}{E}$ = Irrigation requirement at head of the field, in inches.

Culture	Growing season	Consumptive Use			U Minus R	E (%)	I (in.)
		Factor F	Coef. K	Product U			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Alfalfa	May 6 to October 6	31.12	0.85	26.45	21.73	70	31.0
Grass hay	May 6 to October 6	31.12	0.75	23.34	18.62	60	31.0
Corn	May 6 to September 6	26.21	0.75	19.66	16.02	65	24.6
Small grain	May 6 to August 6	19.83	0.75	14.87	12.55	65	19.3
Orchards	May 6 to October 6	31.12	0.65	20.23	15.51	70	22.2
Seeped land	May 6 to October 6	31.12	0.80	24.90	20.18	...	...
Dense natural vegetation	May 6 to October 6	31.12	1.20	37.34	32.62	...	...

Another example is the estimate of rates of water consumption made by the Division of Irrigation and Water Conservation in 1947-1948 in each of the states of Arizona, Colorado, New Mexico, Utah, and Wyoming at the request of the Upper Colorado River Basin Compact Commission.[3] Some of the results

[40] "Consumptive Use of Water in California," by Harry F. Blaney and G. Marvin Litz, Div. of Irrig. Eng., SCS, U. S. Dept. of Agri., Los Angeles, Calif., 1952 (unpublished).

[3] "Consumptive Use of Water in the Irrigated Areas of Upper Colorado River Basin," by Harry F. Blaney and Wayne D. Criddle, Div. of Irrigation and Water Conservation, SCS, U. S. Dept. of Agri., Logan, Utah, April, 1949.

are shown in Table 8. A report was completed in 1948 and several months later a compact allocating a percentage of water to each state, based primarily on consumptive use, was agreed upon by the states and approved by Congress early in 1949.

Summary.—One of the major uses of basic consumptive-use data shown in Tables 2, 4, and 8 is in estimating the water requirement of existing or proposed irrigation projects and in determining the quantity of water required for crop production on individual farms. The water required for irrigation is dependent not only on consumptive use but also on the irrigation efficiency and usable summer precipitation. In some farm-planning programs it is necessary to estimate irrigation requirements of each crop at the point of water delivery to the field. This may be accomplished by dividing consumptive use minus precipitation by field irrigation efficiency, as shown in Table 12. By making an allowance for farm-lateral loss from the farm headgate to the field, the amount of water that should be delivered to the farm headgate may be estimated.

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